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THE EFFECT OF SURFACE ROUGHNESS AND CURING CONDITION ON THE ULTIMATE SHEAR CAPACITY OF COMPOSITE SLAB

OH TECK YEE

A project report submitted in partial fulfillment of the
requirement for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

November, 2009

I declare that this project report entitled "The Effect of Surface Roughness and Curing Condition on The Ultimate Shear Capacity of Composite Slab" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any degree.

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Specially dedicated to my beloved parents and husband.

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Last, thanks are due to the people that I do not mention their name for their assistance and encouragement.

ABSTRACT

This thesis presents the effect of surface roughness and curing condition on the horizontal shear capacity of precast slabs with in-situ concrete toppings. When the composite member is loaded and bent in flexure, they will tend to slide relatively to each other. In the case where mechanical shear key in the form of reinforcement is not provided at the interface of the precast units, the texture at the interface becomes a major parameter to ensure the horizontal shear strength of the contact surfaces is achieved. Furthermore, the effect of concrete toppings under air cured and water cured conditions were investigated due to the practical difficulties in achieving even the minimum specified curing on-site. The experimental results of eight (8) precast units with different surface roughness (smooth, roughened and exposed aggregates) under four point bending test is presented. Interface slip was also measured throughout the test to examine the composite behavior of the composite slabs. Based on the findings, smooth surface produced the highest ultimate shear capacity in water cured condition i.e. 19% - 34% higher than the others. However, rough surface in transverse direction yielded the highest ultimate shear capacity under air cured condition. The tests had clearly shown the effect of difference surface roughness and curing condition to the ultimate shear capacity. Large slip of between 1.0 and 1.3 mm was also observed for the specimen under air cured condition, indicating water cured produce better interface bond. Furthermore, comparison of the experimental shear strength with BS 8110 and Eurocode 2 shows that even the as-cast surface can develop adequate shear resistance. Thus, shear reinforcement is not an essential requirement and the production of precast slabs can be simplified.

ABSTRAK

Tesis ini membincangkan kesan kekasaran permukaan dan kaedah pengawetan terhadap tegasan ricih mengufuk untuk papak pratuang dengan konkrit tuang di-situ. Secara umumnya, papak rencam bergelangsar sesama sendiri di bawah lenturan. Kekasaran permukaan unit pratuang memainkan peranan penting untuk menjayakan tegasan ricih mengufuk di antara permukaan sentuh itu apabila tetulang ricih tidak dipasangkan. Tambahan pula, kesan konkrit tuang di-situ di bawah pengawetan basah dan kering juga turut dikaji memandangkan kesukaran untuk dicapai di tapak bina. Maka, semua faktor-faktor ini akan dikaji dan pengaruh terhadap tegasan ricih mengufuk papak rencam yang diakibatkan oleh kekasaran permukaan berserta dengan cara pegawetan dibincangkan dalam tesis ini. Sejumlah lapan (8) papak rencam dengan kekasaran permukaan yang berlainan (licin, dedahan batu, kasaran melintang dan kasaran panjang) dan cara pengawetan yang berbeza (basah dan kering) dibandingkan dalam kajian ini. Gelinciran di antara komponen turut diukur sepanjang eksperimen dijalankan. Keputusan ujikaji menunjukkan permukaan licin dengan pengawetan air menghasilkan kekuatan ricih yang paling tinggi, 19% - 34% lebih tinggi berbanding dengan permukaan kasar. Manakala, keupayaan permukaan kasar melintang adalah lebih baik berbanding dengan permukaan licin dalam pengawetan kering. Hasilan ini membuktikan bahawa kekasaran permukaan dan cara pengawetan yang berlainan akan menghasilkan kekuatan ricih yang berbeza. Gelinciran di antara 1.0 dan 1.3 mm telah diperolehi untuk spesimen di bawah pengawetan kering, menunjukkan pengawetan basah menghasilkan ikatan antara muka yang lebih baik. Tambahan pula, tegasan ricih mengufuk yang diperolehi dalam ujikaji eksperimen adalah lebih tinggi berbanding dengan tegasan yang dinyatakan dalam BS 8110 dan Eurocode 2. Dengan itu, dapat disimpulkan bahawa tetulang ricih bukanlah suatu keperluan dalam pembinaan papak rencam.

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I_{comp}	Second moment are of the composite section
b_i	Width of the interface
b_w , b_v	Width of the concrete topping
b_{eff}	Effective width
S_{comp}	First moment of area above and about the centroidal axis
f_t	Concrete splitting tensile strength
f_{cp}	Concrete compressive stress at the centroidal axis due to prestressing
f_y	Characteristic strength of reinforcement
f_{ck}	Cylinder compressive strength of concrete = $0.8f_{cu}$
f_{cu} ,f_{cc}	Cube compressive strength of concrete
p	Ratio of tensile reinforcement
w	Uniform load distribution
d	Effective depth of the tension reinforcement
L	Effective span length
a	Shear span
x	Neutral axis
z	Lever arm of composite action
y_t	Distance from the neutral axis of the composite section to half of concrete topping depth
h_t	Concrete topping depth
y_s	Distance from the neutral axis of the composite section to the steel centroid
As	Area of tension reinforcement

As'	Area of compression reinforcement
A	Compression zone being considered
A'	Effective area under normal compressive stress
M_{ur}	Design ultimate bending moment
V_u , V_{ult}	Ultimate shear capacity
V_{ds}	Transverse shear force
V_{co}	Design ultimate shear capacity of a uncracked flexure section
σ_c	Normal compressive stress
σ_n	Stress per unit area
s_n	Imposed slip displacement during the cycle
s_u	Shear slip corresponding to maximum mobilized shear stress
$\tau_{fr,n}$	Frictional stress response to the n^{th} cycle
τ_{ds}	Design shear stress at the interface
τ_{dsr}	Design shear resistance at the interface
τ_{exp}	Experimental shear stress

CHAPTER 1

INTRODUCTION

1.1 Background

Reinforced concrete is concrete in which steel reinforcement bars have been incorporated to give it extra tensile strength. It can be further classified into cast in-situ concrete or precast concrete. Precast concrete is cast and cured in a controlled environment. It is then transported to the construction site and lifted into position. In contrast, precast concrete is having higher standard compare to cast in-situ concrete. Apart from the quality, precast concrete system offers faster erection speed when compared to normal reinforced concrete construction. Erection is carried out with the aid of lifting equipments.

There are many different types of precast concrete forming systems including slabs, walls, beams, columns, foundations, etc. However, main focus is given to floor systems as this is the key to creating optimal building structures. Difference in floor systems may have significant impact on construction schedule and materials cost. Precast concrete flooring offers an economic and multitalented solution to ground and suspended floors in any types of building construction. In order to enhance the structural performance, cast in-situ toppings are added to the precast slab. This composite member is designed to act monolithically. Hence, understanding the behavior of monolithic action of composite member has become a topic of particular challenge to researchers throughout the world recently.

1.2 Problem Statement

The principle of composite construction can be demonstrated by comparing the action of two joists placed one on top of the other. When the precast unit with concrete toppings is bent in flexure, the composite members tend to slide to each other as shown in Figure 1.1.

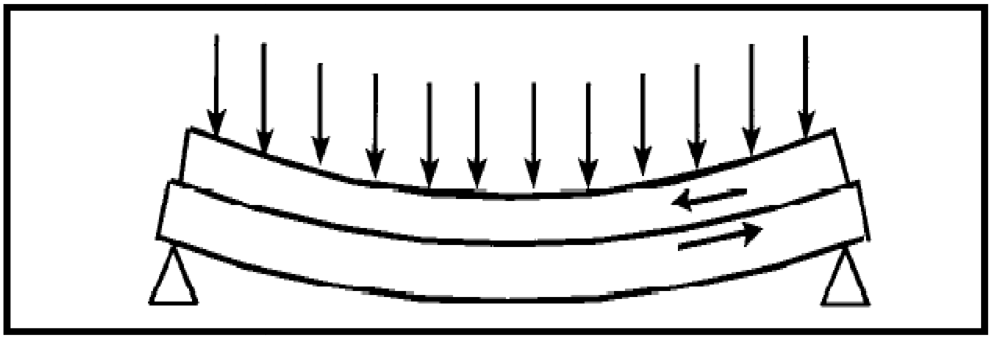

Figure 1.1: Interface Shear Stress of Composite Member

If these composite members are physically connected using mechanical shear key, the bending strength and stiffness will be significantly improved. Nevertheless, reliance has to be made on the shear strength and bond between the contact surfaces without any mechanical shear key.

Figure 1.2: Precast Slab with Extruded Shear Key

Normally, the need for reinforcement across the interface will depend upon several factors: type of surface texture, the loading or geometry of the construction [6]. In the case where joint surface area is having the same area as the topping, it is referred as low shear area at the interface, where the force can be transmitted without shear key as long as adequate interlocking effects are available.

In designing the interface to ensure composite action, several Codes of Practice [2,5,6] have considered surface roughness as the major factor contributing to limiting stresses for different roughness categories. Some attempts to enumerate surface texture are given in the FIP document [6]. The general types of surface texture are smooth and rough. Within the FIP Commission itself, they believe smooth interfaces have better bonding effects compared to the roughened. The design guidance is still lack of congruency especially at the serviceability limit state.

Other than surface texture, surface preparations may cause problems and affect the monolithic behaviour of the composite member. According to the research work carried out by Walraven [16], the precast slab surface preparation will affect the capacity of the interface shear strength. This includes reductions to the interface shear strength and lead to occurrence of interface slip.

The other common problem associated with concrete industry is cracking problem. The most common causes of cracks in concrete are: stress due to applied loads or stress due to drying shrinkage or temperature changes. Stress cracks can be easily eliminated by having proper concrete design for the load. However, drying shrinkage is an inescapable and inherent property of the concrete. To minimize these cracks, proper curing to hold the moisture is obligatory. As long as the moisture in concrete is trapped for certain period, and that adequate tensile strength is allowed to gain in concrete for this particular period, the concrete is unlikely to shrink [1].

Two major parameters will be focused in this study i.e. surface texture of the precast slab and the curing technique applied for the concrete topping. The effect of these parameters on the interface shear strength shall be examined.

1.3 Objectives

The objectives of this study are as follows:

(i) To study the structural performance of composite slab with different surface roughness

(ii) To evaluate the interface shear strength of the composite slab for different curing condition

(iii) To compare the experimental shear stress result with the minimum horizontal shear stress provided in BS 8110 and Eurocode 2

1.4 Scopes of Study

The endeavor of this project is to study the interface shear strength between the 100 mm thickness precast solid slab and 75 mm thickness concrete toppings with different surface roughness and curing conditions. A total number of eight precast units will be prepared in this study. The performance of these specimens will be assessed through the shear capacity and load-deflection relationships of the composite slabs under the combined bending and shear test.

Since the precast concrete slab surface is not provided with any shear mechanical key, the texture of the interface of the precast units becomes the key parameter for determining the interface shear strength of the composite members. It is vital to study what kind of surface can produce better bond at the interface. Therefore, eight composite slabs with four different types of surface roughness (smooth as-cast, roughened in both the longitudinal and transverse direction, and surface with exposed aggregate) were prepared.

It is obvious that curing method affect significantly the performance expected from specified water/cement ratio and cement content. In reality, it is always difficult to cure concrete satisfactorily due to some practical problems especially when the surface area is large. Hence, the concrete toppings of these eight specimens shall be further categorized into two curing conditions i.e. air cured and water cured. Air cured represents the actual poor curing practice at construction site and the effect on the shear strength in lieu to this condition will be studied. Meanwhile, all the precast slab units will be water cured as practiced by the manufacturer.

In the combined bending and shear test, a pair of point loads was applied at 1.5H from the support at both ends, where H is the overall depth of the composite slab. The interface slip of the longitudinal joints will be monitored throughout test.

1.5 Importance of Study

The study is intended to determine the most suitable casting method according to different surface characteristic and curing conditions. Appropriate casting method may reduce the remedial work due to delamination, loss of serviceability or curvature problem associated with concrete toppings. By improving the composite performance, the overall construction cost and maintenance cost can be reduced.

1.6 Thesis Structure

The structure of this thesis is as shown below:

(a) Chapter 2 describes a review of the literature on the subject of this project
(b) Chapter 3 presents the preparation work for the specimens and the experimental setup for combined bending and shear test
(c) Chapter 4 interpret the experimental results
(d) Chapter 5 presents the analysis and discussion of the results
(e) Chapter 6 presents the conclusions and the recommendations for further investigation

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For full composite action of the precast slab with concrete topping, the shear and bond strength of the interface between the two elements are critical. Various international codes of practice recommend different allowable interface shear strengths depending on the surface characteristics. Whereas, the relationship between shear, surface roughness and bond strengths of interfaces in different composite concrete structures have been investigated by many researchers in the previous studies. The results and findings shall be discussed in detail in the following sections.

2.2 Shear Capacity of the Interface

To retain the continuity and efficiency of monolithic construction, composite construction is the most cost-effective way of combining precast and cast in-situ concrete. The monolithic behavior is possible only if the horizontal shear is effectively transferred between the topping and precast slab at their interface. When the composite member is bent in flexure, they tend to slide with each other respectively. For ensuring the horizontal strength is achieved, shear connector is provided at the interface to transfer the force and act as an interlocking device. In the case where no mechanical key is provided, reliance has to be made on the bond and shear strength between the contact surfaces.

In 1991, Ueda and Stitmannaithum [15] conducted an experimental program to investigate the shear-carrying capacity of precast prestressed hollow core slabs (HCU) with concrete topping. Ten specimens were prepared and the study parameter includes pre-stressing force, tension reinforcement ratio, shear span-to-effective-depth ratio and the concrete topping depth. In their experimental investigation, two types of shear cracking were observed; web shear cracking and flexural shear cracking. In the prediction of ultimate shear capacity, reference was made to the formula proposed by Niwa [11] for ordinary reinforced concrete beams (a/d < 2.5) and the modified formula proposed by Okamura et. al. [12] for ordinary reinforced concrete slender beams (a/d > 2.5) without shear reinforcement. These formulas are given as:

$$V_u = 0.244 {f_{ck}}^{\frac{2}{3}} \left(1 + \sqrt{\rho}\right) \left(1 + 3.33 \frac{w}{d}\right) \frac{1}{1 + \left(\frac{a}{d}\right)^2} b_w d \qquad \text{if (a/d < 2.5)} \qquad (2.1)$$

$$V_u = 0.20 {f_{ck}}^{\frac{1}{3}} (100\rho)^{\frac{1}{3}} (1000/d)^{\frac{1}{4}} (0.75 + \frac{1.4}{\frac{a}{d}}) b_w d \qquad \text{if (a/d > 2.5)} \qquad (2.2)$$

They observed in their tests complete composite action although only rough surface finishing was provided. Small slips were measured between the precast and topping concrete elements, and there was no evidence that the interface was an initiator of ultimate failure. For both the thick and thin concrete topping, web shear cracking always took place in the precast element at the level of the hollow where the narrowest web width was found. Because of the circular hollow, the highest principle tensile stress – resulting from the combination of shear stress and flexural stress due to the external applied load, as well as the compressive stress due to the effective prestressing force – can be found at the narrowest web instead of that of the centroidal axis depth. The comparison between the calculated and experimental results shows good agreement. Ueda [15] suggested that the equations used to calculate the ultimate shear capacity for ordinary reinforced concrete beams without shear reinforcement can also be applied to the HCU with concrete toppings by using the strength of the concrete toppings and its width in the prediction.

2.2.1 Surface Roughness

In the FIP Guide to Good Practice (FIP 1982) [6], there are ten categories of surface roughness in which a precast unit may have prior to the casting of the in-situ concrete toppings. They were categorized based on the end production and there is no clear guidance to differentiate between the rough and smooth surface. Nevertheless, FIP Commission itself believes that smooth interface always provide better overall bonding than rough surfaces. According to Swedish Standard [13], a measuring device as shown in Figure 2.1 is used to measure the surface roughness of a member. The measuring device shall be placed along one measured line at a time and the gauge is read. The measurement procedure is based on procedure given in BS1134 [3]. The roughness amplitude represented by R_a is the arithmetical mean deviation of the profile, taking the average value of the surface profile shown in Figure 2.2.

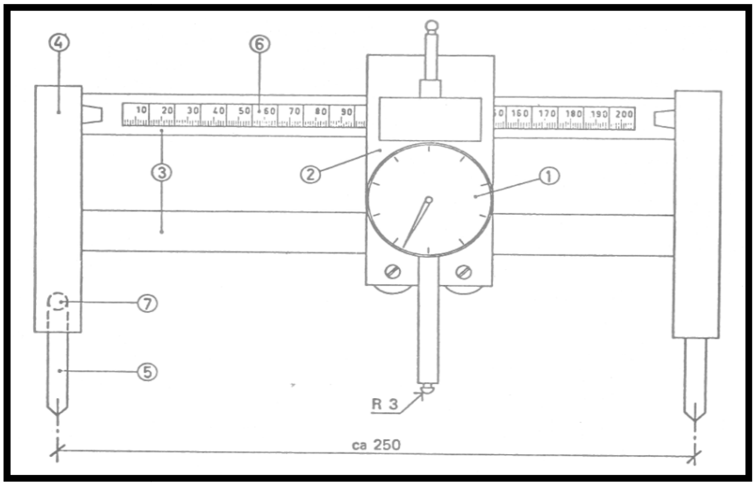

Figure 2.1: Measuring Device for Measuring Surface Roughness

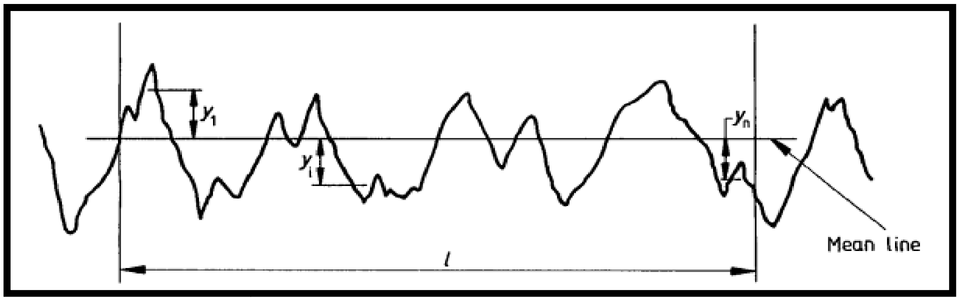

Figure 2.2: Arithmetical Mean Deviation of the Profile, R_a

The departure of the profile is represented by y_1 to y_n, where n is the number of profile departures. The equation of R_a given by:

$$R_a = \frac{1}{l}\int_0^l [y(x)]dx \tag{2.3}$$

or approximately,

$$R_a \approx \frac{1}{n}\sum_{i=1}^{n}(y_i) \tag{2.4}$$

In practice, the values of R_a are determined within the evaluation length which covers several sampling lengths, l, i.e. equal to the cut-off point. In the work by Mitchell Gohnert [7], similar roughness measurement was used to determine the roughness for smooth and rough surfaces. The work shall be further discussed in the following section.

2.2.2 Previous Work Related to Surface Roughness

In 1987, Theodossius & Elisabeth [14] studied the mechanism of load transferred along unreinforced concrete interfaces by means of friction for several surface roughnesses. The behavior of both smooth and rough interfaces of plain concrete subjected to monotonically or cyclically impose shear displacements was investigated through several series of tests. Unreinforced concrete blocks of 0.90 m long x 0.30 m height x 0.15 m wide were cast in metal molds. During concreting, two grooves with 15 mm deep and 300 mm long were provided at each face of the specimen. Before testing, the specimens were cracked by splitting. Thus, between adjacent concrete sub-blocks, two interfaces were formed as shown in Figure 2.3.

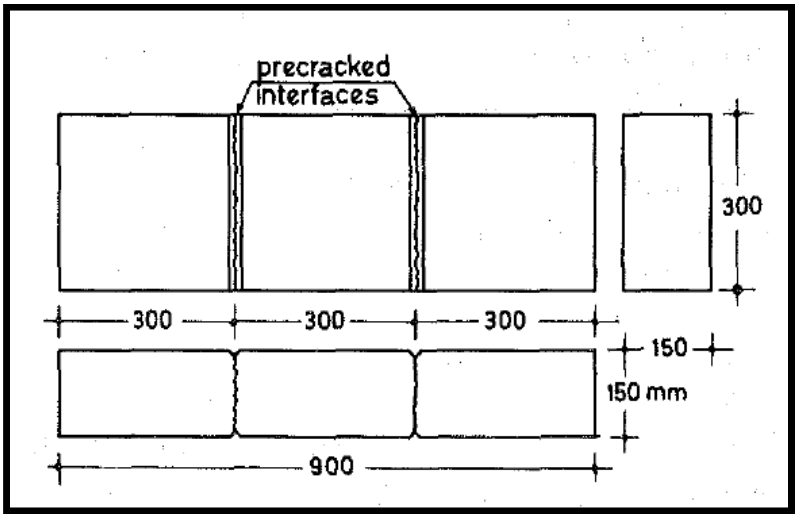

Figure 2.3: Specimen Details

The three concrete sub-blocks were held together by means of four external steel rods, 30 mm in diameter. Schematic diagram of the experimental setup is as shown in Figure 2.4. The tests were displacement-controlled so that the falling branch of the shear stress versus shear displacement diagram is obtained. Shear displacement was imposed by means of mechanical jacks and the response of the specimen was measured by using load-cells. Test parameters which were experimentally investigated are summarized in Table 2.1.

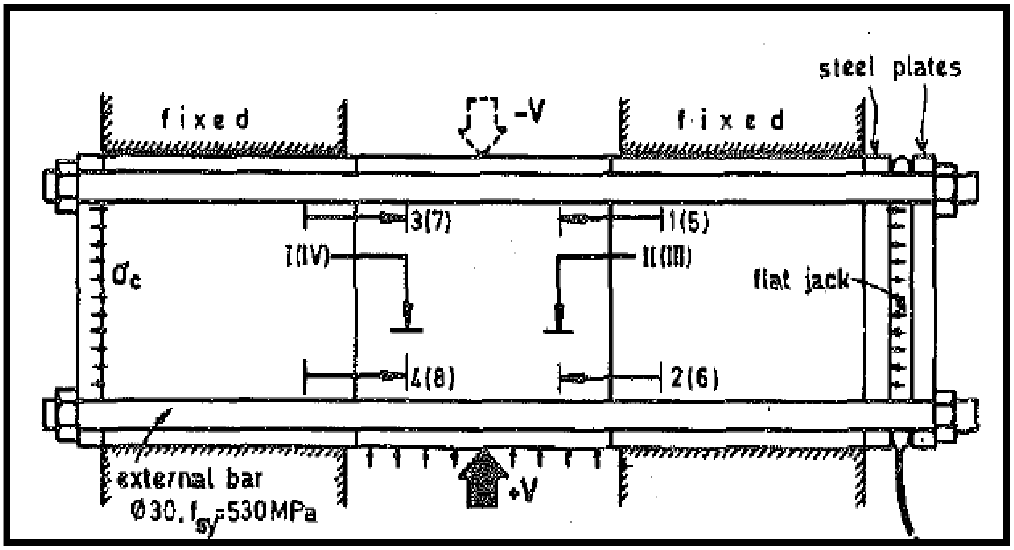

Figure 2.4: Schematic Diagram of Experimental Setup